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HIGHWAY RESEARCH REPORT

DYNAMIC TESTS OF AN ENERGY ABSORBING BARRIER EMPLOYING SAND-FILLED FRANGIBLE PLASTIC BARRELS

By
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and Robert N. Doty

Presented at the 51st Annual Meeting
of the Highway Research Board
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State of California
Department of Public Works
Division of Highways
Materials and Research Department

DYNAMIC TESTS OF AN ENERGY ABSORBING BARRIER EMPLOYING SAND-FILLED FRANGIBLE PLASTIC BARRELS

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ABSTRACT

REFERENCE: Nordlin, E. F., Stoker, J. R., and Doty, R. N., "Dynamic Tests of an Energy Absorbing Barrier Employing Sand-Filled Frangible Plastic Barrels", State of California, Department of Public Works, Division of Highways, Materials and Research Department Research Report HRB 636405-4.

ABSTRACT: The results of three full scale vehicle impact tests into energy absorbing barriers employing sand-filled frangible plastic barrels are reported. The barriers were designed for placement in front of fixed objects located in freeway gores. They were composed of an array of 15 to 17 cylinders 36 inches in diameter by 30 and 36 inches high. The barriers were 21 ft and 25 ft long and tapered from a 3 ft width at the nose to a 9 ft width at the rear. The barrels were not attached to the ground.

Sedans weighing approximately 4700 lbs. and traveling approximately 60 mph impacted the nose of the barrier head-on and at a 15 degree angle. A small sedan weighing about 1900 lbs. also impacted the nose of the barrier head-on at 59 mph. The vehicular passenger compartment decelerations were considered tolerable for lap-belted passengers and would have resulted in no more than moderate injuries in most cases. However, the computed Gadd Severity Index for the lap-belted dummy driver in the light sedan indicated "fatal" head injuries were incurred.

The vehicles remained relatively stable during all three impacts. The 4700 lb. vehicles penetrated the barrier with low exit velocities after sustaining moderate damage.

Most of the barrels in each barrier were demolished during each test. The debris scatter in the lateral direction during the head-on impact was minimal except for the lids. The angle impact into the barrier nose caused considerable amounts of sand and broken barrels to be thrown into the "traveled way".

The barrier was judged acceptable in the areas of cost, ease of construction and maintenance, aesthetics, simplicity, and versatility, and is recommended for use in operational trial installations.

KEY WORDS: Barriers, dynamic tests, impact tests, attenuation, bumpers, cushioning, energy absorbers, kinematics, vehicle dynamics.

ACKNOWLEDGEMENTS

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, as Item D-4-69 of Work Program HPR-PR-1(8), Part 2, Research. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

The following staff members of the Materials and Research Department were instrumental in the completion of the tests reported herein:

Roger Pelkey Roger Stoughton Orvis Box Lee Staus Joe Eagan Dale Sathre	Construction of barrier, preparation and operation of test vehicle and other test equipment and assembly of the test data.
Bill Chow Merle Wilson Delmar Gans William Ng	Instrumentation of test vehicles and dummies.
Robert Mortensen	Data and documentary photography.
George Oki	Fabrication of Volkswagen tow system components.

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I. INTRODUCTION

General

During 1967 and 1968, approximately 25% of all the fatalities on the California freeway system were caused by vehicles running off the road and colliding with fixed objects such as bridge piers and large sign posts. Consequently, the California Division of Highways now strives to provide a 30 ft wide recovery area alongside the traveled way clear of fixed objects. Whenever possible, those fixed objects that cannot be removed from this recovery area are made "breakaway". However, one problem that has defied effective solution has been that of gore areas of freeway off-ramps which contain large sign posts, bridge rail end posts, and other rigid structures. Various types of energy absorbing barriers have been proposed for installation in front of or around these fixed objects to cushion vehicular impacts. The California Division of Highways has conducted full scale crash tests of two of these types, namely, barriers incorporating water-filled plastic cells and barriers incorporating empty, 55 gallon steel oil drums[1,2]. Another proposed solution to this problem consists of placing an array of sand-filled frangible plastic barrels between the traveled way and the fixed object. Three tests of this type of barrier are reported herein.

Background

The object of the tests reported herein was to assess the effectiveness of a barrier developed by John Fitch and manufactured by Fibco, Incorporated, of Hartford, Connecticut. During 1967 Fitch conducted over thirty crash tests of impact attenuators utilizing sand supported on various types of material. Fitch himself drove the test vehicle during some of these tests at speeds of up to 60 mph. This series of tests was supported by a few interested firms and engineering assistance was provided by the New York State Department of Transportation. The tests proved the feasibility of using the concept of momentum transfer from the impacting vehicle to the sand but the need for a more sophisticated system for containing the sand became evident. A weatherproof, cylindrical, plastic barrel was developed that would provide lateral support for the sand but would shatter relatively easily when struck by an impacting vehicle. The barrel material was a high density polyethylene produced using a structural foam process.

In April 1969 Fitch conducted another series of six tests. This phase of his testing was supported by the State of Connecticut under the auspices of a National Highway Safety Board project grant. The tests were conducted at speeds of 40-50 mph using vehicles weighing 1700, 3000, 3500, and 3900 lbs. The test barriers were 14'-6" to 25'-0" long. A live driver was used in two tests. The barrels were placed in an open area with no fixed object behind the barrier. In all the tests except those with a 1700 lb. car, the stopping distance exceeded the barrier length. Reports of the tests indicated that the test vehicles were decelerated in an effective, stable manner; however, there was no instrumentation to measure peak G's on the vehicle. Also of concern was the amount of debris that would be generated as the barrier decelerated an impacting vehicle.

Subsequent to the above tests, Fitch barriers had been installed at locations in several states. A few collisions with these barriers had been recorded with generally favorable performance. Thus, the sand inertial barrier concept appeared promising due to its apparent effectiveness in adequately decelerating impacting vehicles, adaptability to varied site conditions, simplicity, and relatively low first cost. However, due to the limited number of formally documented tests that had been conducted, a series of 60 mph tests using instrumented, relatively heavy and light vehicles was deemed necessary to more accurately evaluate the barrier's effectiveness.

II. OBJECTIVE

The objective of this research was to conduct instrumented vehicular impact tests of energy absorbing barriers incorporating sand-filled plastic containers and, based upon the results of these tests, determine the degree to which these barriers would minimize the hazards created by many existing gore separation structures and other fixed objects. The criteria itemized below were used to evaluate the barrier design:

1. The impact severity for the occupants of errant vehicles involved in head-on collisions into fixed objects located in gores must be reduced to a survivable level at impact velocities of 60 mph and less.

2. The barrier components should not be susceptible to dislodgement or ejection onto the traveled way when an impact occurs, such that they become a hazard to adjacent traffic.

3. First cost and maintenance costs should be economically feasible.

4. On-site repair time should be minimal because of the safety hazards to maintenance personnel and adjacent traffic when field repairs are in progress.

III. CONCLUSIONS

The results of the three full scale tests reported herein indicate that the hazards presented by many existing gore separation structures and other fixed objects can be significantly reduced by providing protection with energy absorbing barriers incorporating sand-filled plastic barrels.

The electronically measured vehicular and dummy decelerations, confirmed by analysis of the photographic data, indicated that occupants of full size vehicles (4700 lbs. including occupants) impacting these barriers at 60 mph will, in most cases, sustain little or no injury if wearing a lap belt and shoulder harness, minor injuries if wearing only a lap belt, and moderate injuries if unrestrained. However, occupants of smaller vehicles such as a 2000 lb. Volkswagen may sustain serious injuries, even if restrained by a lap belt. As this barrier will provide no significant vehicular redirection, the lateral decelerations sustained during collisions with the barrier will be minimal.

Confinement of the sand will result in a tendency for an impacting vehicle to rise. Thus, the modules placed near the rear of the barrier should not be full (eliminate the relatively ineffective lower foot of sand) and a two foot wide void should be provided between the rear of the barrier and the face of the fixed object to prevent accumulation of barrier debris and the associated formation of a ramp adjacent to the fixed object.

A considerable amount of debris will be generated during a 60 mph collision with this barrier. However, most of this debris will be propelled straight ahead of the impacting vehicle. Thus, this debris will present a hazard for adjacent motorists only when high speed, oblique angle impacts occur unless the debris is scattered by wind. Tieing the lids together and encasing the core material will improve this debris problem somewhat.

The reported first cost of approximately 20 installations of this barrier in Connecticut ranged from $1500 to $3300 each[3]. Each barrel used for the <u>test</u> barriers cost $130. Thus, the material cost for the test barriers was approximately $2000 as the test barriers contained 15 and 17 modules each. Although little or no routine maintenance should be required, even relatively mild impacts will almost always require replacement of at least several barrels. However, the simplicity of the barrier's construction will permit minimal on-site repair time after the debris removal operations are complete.

IV. TEST PROCEDURE

Test Site

All three tests were conducted on a section of runway at the Lincoln Municipal Airport located near Lincoln, California.

Test Vehicles

The full size vehicles used were 1968 Dodge sedans. Including dummies and instrumentation, the vehicles weighed approximately 4700 lbs. Control of the vehicles along the impact course was accomplished by a remote operator following 200 feet behind the test vehicle in a control car equipped with a tone transmission system. A trip line in the path of the test car was used to cut off its ignition 10 feet prior to impact. The brakes were not applied before or during impact. A more complete description of the remote control equipment is contained in Reference 4.

A 1957 Volkswagen was used for one of the tests. It was steered and braked by remote control from a follow car as in the other two tests; however, it was incapable of accelerating to 60 mph under its own power within the confines of the test site so a cable tow system was devised to pull the VW into the barrier. A description and some photographs of this system are included as Appendix A, Reference 5.

Test Dummy

One anthropometric dummy was placed in the driver's position. This 165 lb. dummy, representing a 50th percentile male, was restrained with a conventional lap belt. Another, larger anthropometric dummy weighing 210 lbs. and representing a 95th percentile male was placed on the passenger side of the front seat for one of the tests. See Plate 1, page 7, for the location and description of the instrumentation on the dummies.

Photographic Coverage

All the tests were recorded with high speed (250-400 frames per second) Photosonic motor-driven cameras which were manually actuated from a central control console. These cameras were located on the ground on both sides of the barrier, on a 30 ft high light standard directly above the barrier and in the rear of the test vehicle. A motor driven Hulcher camera with a speed of approximately 20 frames per second was located on scaffolding. It provided documentary coverage of the tests. A ground mounted high-speed camera and a normal-speed camera were hand panned through impact. Still photos, slides, and documentary movies were also taken.

Data Acquisition and Processing

Four accelerometers were mounted on the driver dummy, four accelerometers were mounted on the vehicle, and one seat belt transducer was used on the driver dummy's lap belt. The accelerometers used were all of the unbonded linear strain gage type. See Plate 1, page 7, for the location and description of this instrumentation. Signals from three strain gages on the bridge approach guardrail were also transmitted by cable to the tape recorder for Test 241 (Plate 2, page 8).

After a test, the tape was played back through a Visicorder which produced an oscillographic trace (line) on paper. Each paper record contained an accelerometer data trace, a front and rear wheel event marker trace, and a 100 millisecond time cycle trace.

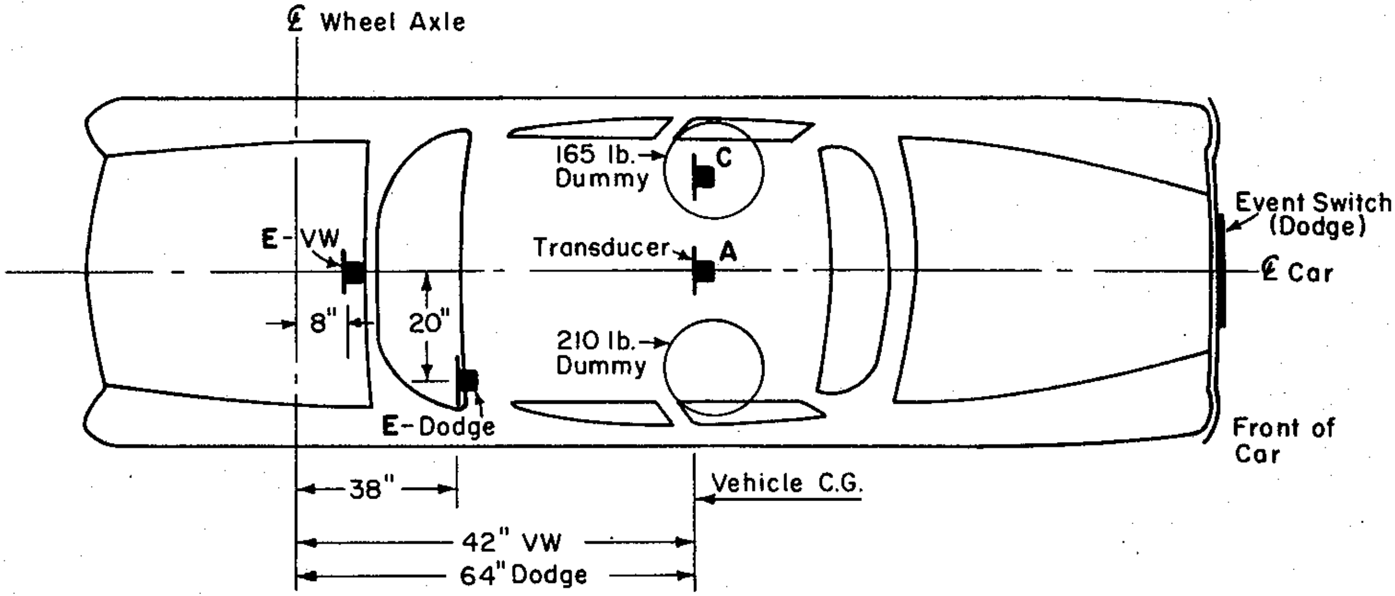
For Test 241, a Krohn-Hite filter was used to obtain data filtered at a rate of 100 Hertz. These filtered traces were easier to compare and to use for data reduction than the unfiltered traces. They also gave a better over-all record of the motion of the dummy and vehicle. The high frequency spikes on the unfiltered records were assumed to be relatively insignificant as related to the over-all motion of the vehicle.

After the data from Test 241 had been filtered, there was a malfunction of the Krohn-Hite filter so a Brush brown dot galvanometer with a frequency response of 22 Hertz was used to obtain an effective filtration rate of 176 Hertz for Tests 242 and 243. However, this filtration rate proved to be too unwieldy for numerical work so a "hand filtered" line was superimposed on it. This eliminated the high frequency spikes and permitted the computation of the maximum deceleration values given in the test results. Copies of the filtered records of impact data for all the tests are contained in Appendix E, Reference 5.

Plate 1

CALIFORNIA DIVISION OF HIGHWAYS

VEHICLE INSTRUMENTATION



Tests 241 & 243
(Dodge)

CHANNEL NO.	LOCATION[1]	DESCRIPTION
1	C	Longitudinal accelerometer - head.
2	C	Lateral accelerometer - head.
3	C	Vertical accelerometer - head.
4	C	Longitudinal accelerometer - chest.
5	A	Longitudinal accelerometer.
6	A	Lateral accelerometer.
7	E	Longitudinal accelerometer.
8	E	Lateral accelerometer.
9	C	Seat belt transducer - lap belt.
13	L	Event switch mounted across front bumper.
	E	Impact-O-Graph with mechanical stylus.

Test 242
(Volkswagen)

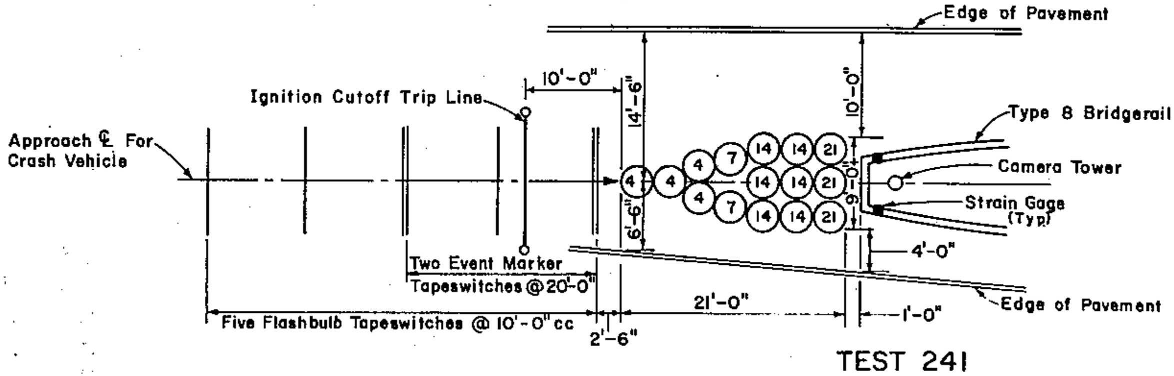
1	C	Longitudinal accelerometer - head.
2	C	Vertical accelerometer - head.
3	C	Lateral accelerometer - head.
4	C	Longitudinal accelerometer - chest.
5	A	Longitudinal accelerometer.
6	E	Longitudinal accelerometer.
7	A	Lateral accelerometer.
8	E	Lateral accelerometer.
9	C	Seat belt transducer - lap belt.

Note:

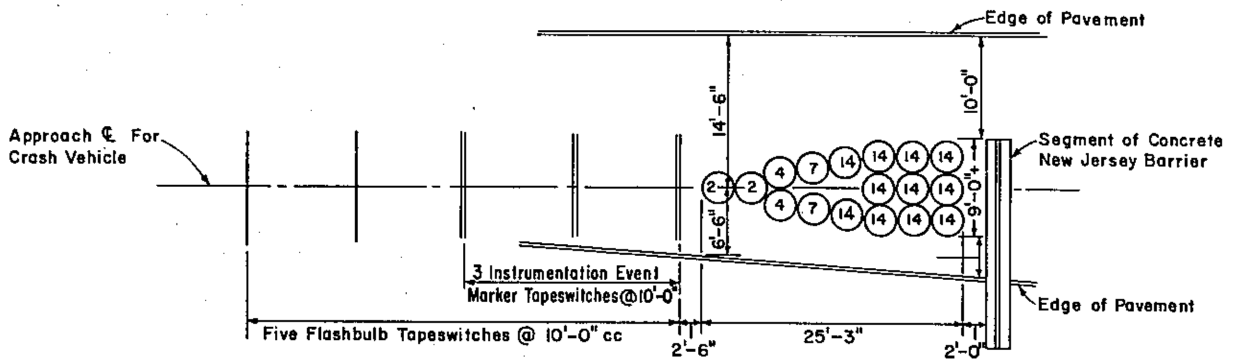
[1] A and E on vehicle floor; C on back of dummy's chest cavity and back of dummy's head cavity.

PLATE 2

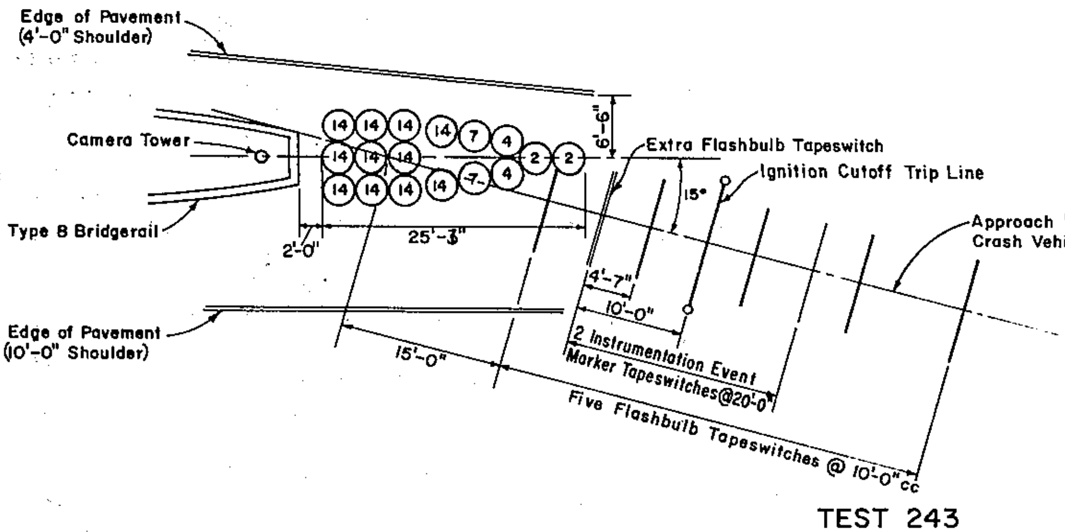
BARRIER INSTRUMENTATION



TEST 241



TEST 242



TEST 243

LEGEND

● – Strain gage on top surface of upper and lower rails, 8 in. behind nose of bridgerail – total 3

(14) – Barrels with nominal wt. of sand in hundreds of pounds.

V. DESCRIPTION OF TEST BARRIER

Introduction

The test barrier for Test 241 was composed of an array of frangible plastic barrels containing varied amounts of sand and was placed in front of a California Type 8 Bridge Approach Guardrail (BAGR - see Figure 1 and Exhibits 1 and 2). Deceleration of the impacting vehicle was obtained through a transfer of momentum from the vehicle to the sand. The foamed plastic used for the barrels was frangible so the sand was relatively unconfined when the modules were subjected to an impact-type load. Thus the barrier design was based on the conservation of momentum with adjustments so that standard barrel sizes could be used. The over-all barrier length for the first test was 21 ft ±. An additional 1 ft gap was left between the rear of the barrier and the nose of the BAGR to provide some additional deceleration distance and to minimize the accumulation of sand against the BAGR (might provide a ramp for the vehicle).

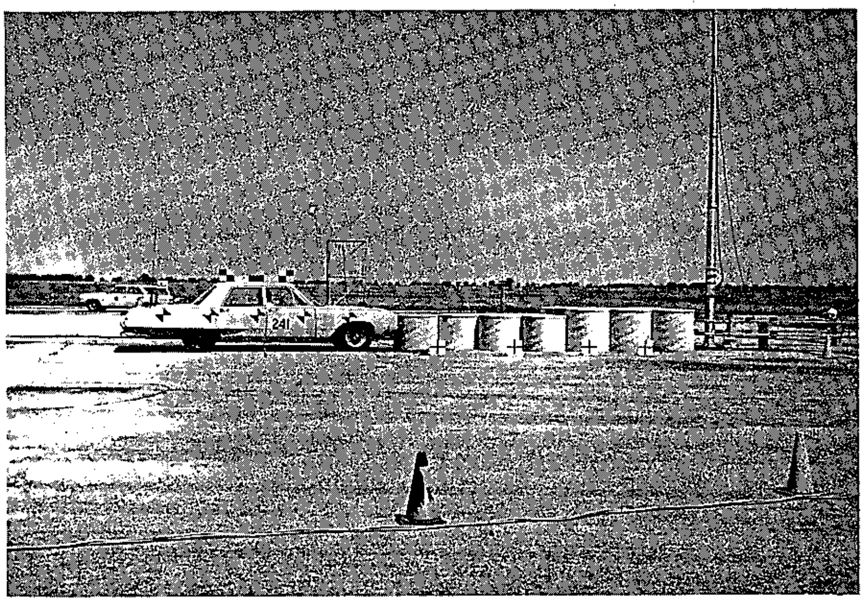
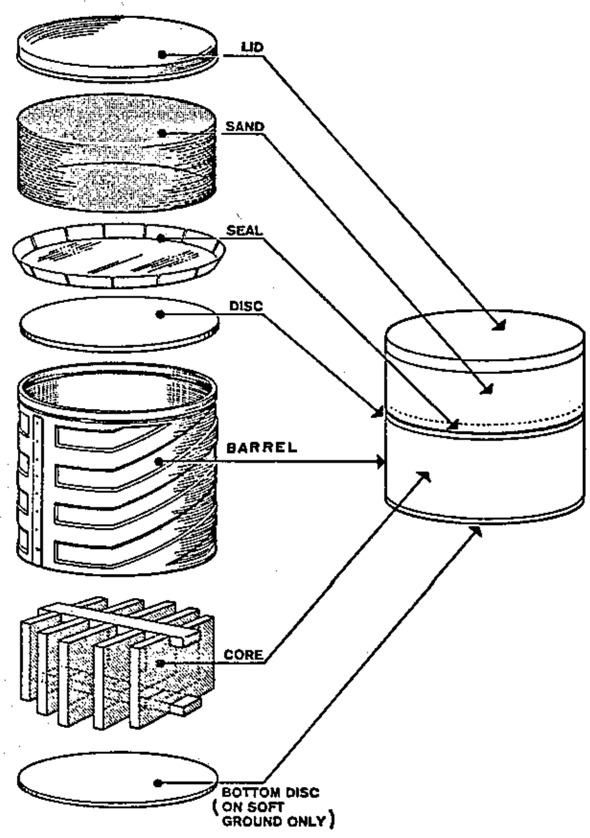


FIGURE 1

Barrier Module

Several components were used to construct each barrel (Figure 2). Frangible, high density polyethylene plastic was used as the barrel material and a thin flexible plastic was used for the lids. A round plastic disc was available to place at the bottom of the barrel on soft ground; however, it was unnecessary for the test barrier. An interlocking group of seven polystyrene (plastic) boards served as a core to support the sand at the proper height in the barrel. Covering the core was a thin, hard, circular, high impact polystyrene (plastic) disc. A flexible clear plastic circular seal with upturned edges was seated on top of the disc to prevent the sand from spilling down to the ground. The sand was poured into the barrel to obtain the desired weight and then a lid was riveted to the barrel in three or four places. Core heights available from the manufacturer permitted nominal sand weights (based on a sand density of 100 pcf) of 200, 400, 700, and 1400 lbs.; a full barrel (with no core) contained 2100 lbs. of sand. The barrels holding 1400 and 2100 lbs. of sand were 3' in diameter and 3' high; all other barrels were 3' diameter and 2'-6" high.



BARREL COMPONENTS

FIGURE 2

Barrier Design

The initial barrier (Test 241) was constructed using barrels containing 400 lbs. of sand at the nose and 2100 lbs. of sand at the rear (see Exhibit 1 and Figures 3 and 4). This mass distribution was designed to obtain a relatively uniform rate of deceleration during impacts. The barrier had a width of 3 ft (one barrel) at the nose and was tapered out to a width of 9 ft (three barrels) at the rear.

FIGURE 3

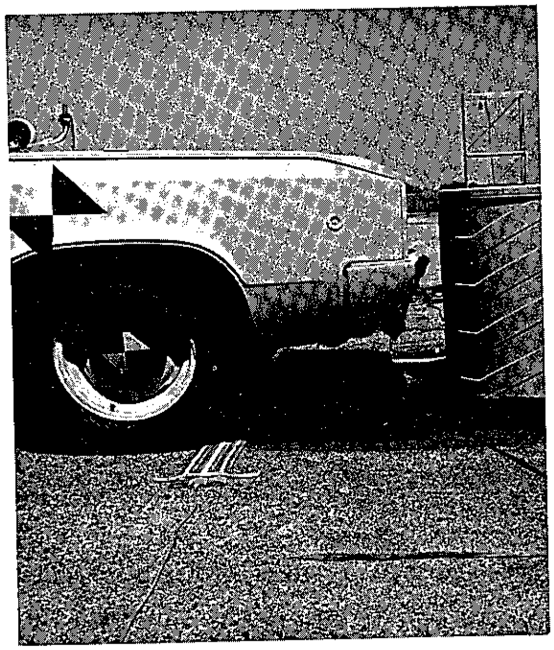


FIGURE 4

Simulated shoulder lines were placed 10 ft off the left side of the barrier and four feet off the right side as measured at the last row of barrels. These dimensions represented a four lane freeway with a two lane off ramp as per the California Division of Highways' Planning Manual. The simulated gore area was 23 ft wide at this point. See Appendix B and Appendix C, Reference 5, for instructions on installing the barrier and for notes on the assembly of the test barriers.

VI. TEST RESULTS

Test 241

Test Vehicle

A 1968 Dodge sedan weighing 4690 lbs. was used as the test vehicle. The 4690 lbs. included a 165 lb. dummy placed in the driver's seat and a 210 lb. dummy placed on the passenger side of the front seat. Both dummies were restrained with lap belts. The left front door and the gas tank were both removed prior to the test.

Vehicle Behavior and Damage

See Plate 3, page 15, for a summary of the test results. The vehicle, traveling 58 mph, impacted the barrier head-on and plowed through the entire barrier (Figures 5 and 6). The vehicle axis was one ft. to the left of the barrier axis at the time of impact. About 3-4 feet in front of the bridge railing, the vehicle ramped up on barrier debris and came to rest on the bridge rail just in front of the camera tower 24 ft behind the nose of the barrier. As it ramped up, the vehicle tilted sharply in a counterclockwise direction, since the left front wheel was off the bridge rail, and almost turned over (Figure 7) before returning to its final position. The left rear fender was flush with the ground when the vehicle came to rest.

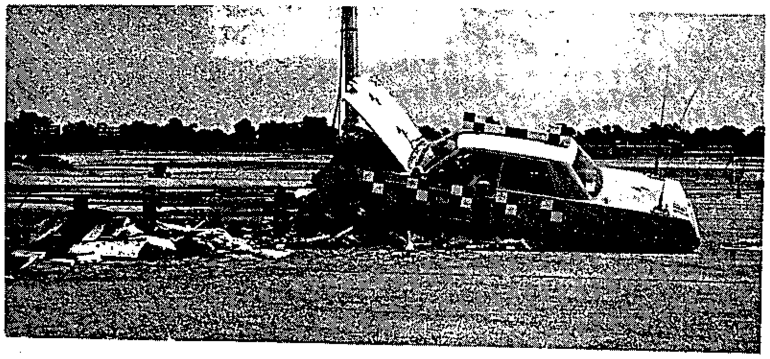


FIGURE 5

FIGURE 6

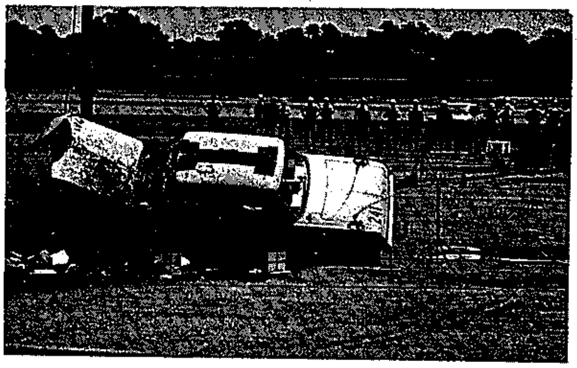


FIGURE 7

Damage was confined mainly to the front end. Maximum significant crush at the center of the vehicle forestructure was 1'-8". The crush was fairly uniform across the front of the vehicle but slightly less on the left side (see Figure 8 and Exhibit 3). The lower frame member, bumper, and front fenders were all severely buckled and the radiator was shoved back against the engine. On the passenger side, the front windshield was cracked where the sun visor came down and was struck by the dummy's head. No crimp in the roof over the doorpost was observed. The doorpost on the driver's side was torn loose from its roof connection and displaced back ½". Immediately after impact, the hood flew open. However, it sustained no damage, mainly because the level of the hood was higher than the 2'-6" high barrels at the nose of the collapsible barrier. The steering wheel deformation was 2½"; the collapsible steering column was foreshortened 0.7" when the jackknifing dummy hit it.

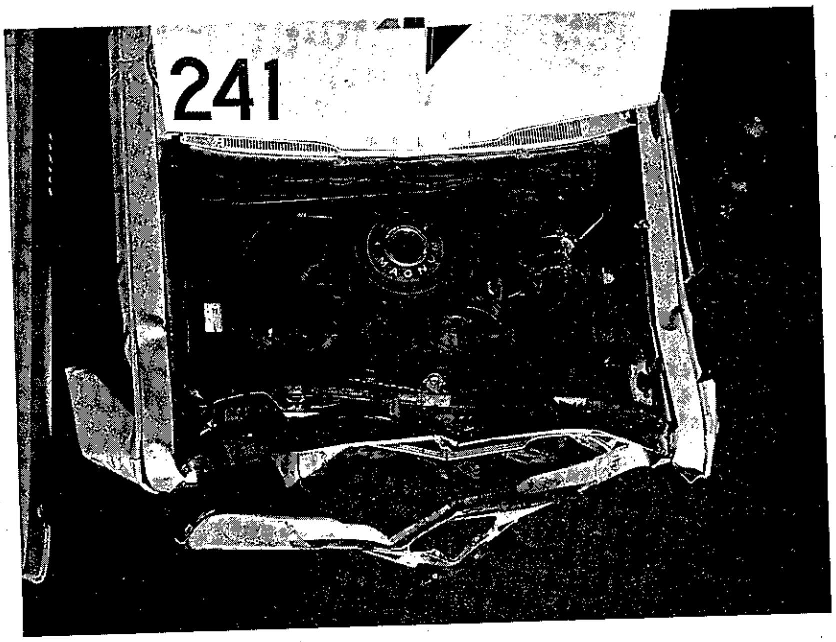


FIGURE 8

Barrier Damage

Most of the broken foam plastic core pieces stayed under the vehicle. No lids were broken. However, all the lids were detached from the barrels and several were displaced a considerable distance. Broken barrel fragments did not travel far; four barrels along the right side of the barrier were mostly intact. They had been shoved sideways and tipped over, spilling sand out rather than "exploding". It appeared that most of the barrier resistance came from the left two-thirds of the barrier. Other than lids, little debris flew outside the "edge of pavement" lines except for some sand which extended 4-6 feet into traffic lanes on each side, beside the original barrier location on the right side and 10-15 ft beyond it on the left side (see Plate 4, page 16). The last one or two rows of barrels did not shatter but leaned and compressed against the bridge rail and then fractured. These barrel pieces, plus the sand which was intermixed, piled up in front of the bridge rail and provided a ramp for the car to climb up on the bridge rail. The broken plastic core pieces were small and mixed into the sand; hence, the sand did not appear suitable for reuse without sifting. Most of these fragments remained in the debris under the vehicle; however, many pieces on top of the pile were scattered quickly by the wind. This condition could pose a psychological hazard to drivers on an adjacent traveled way as they tried to dodge the pieces and other litter near the gore area.

Instrumentation Results

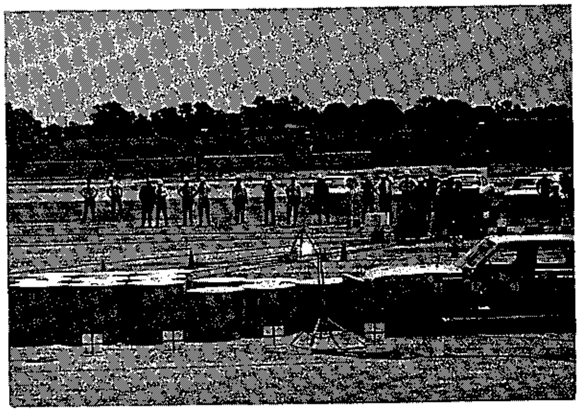
The accelerometer records were cut off about 200 milliseconds after impact on some of the channels when equipment in the test vehicle broke loose. It appeared, however, that in many cases the main pulse of the deceleration was recorded before the interruption. Using Visicorder traces filtered at 100 Hertz, the maximum average values of deceleration were as follows:

1.	Vehicle - longitudinal - highest 50 ms avg. (1 accelerometer - Location E)	10.7 G's
2.	Dummy driver - head - highest 50 ms avg. (resultant of long. and vert. accelerometers)	25.2 G's

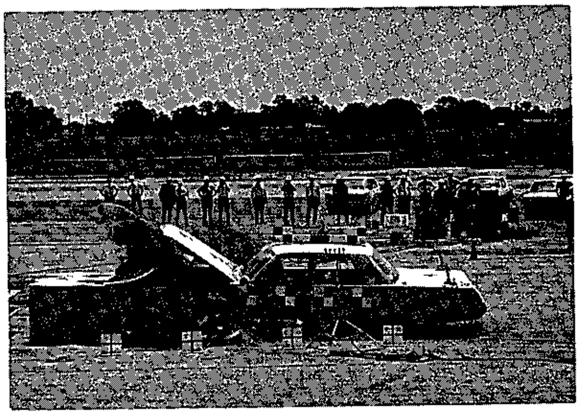
A maximum lap belt load of 990 lbs. was recorded with the seat belt force transducer. Thus, the total load on the dummy was well below the 5000 lb. maximum permitted by federal standards[6]. The tubular steel bridge approach guardrails sustained stresses of 3240, 3620, and 6120 psi -- not excessive values. The highest 40 ms average vehicular longitudinal deceleration was 11.7 G's, just under the maximum value of 12 G's recommended by the Federal Highway Administration[7]. Records from the longitudinal and lateral accelerometers placed at the center of gravity of the vehicle (Location A) were cut off just before the main peak about 200 ms after impact.

The Gadd Severity Index was computed using longitudinal and vertical deceleration components of motion from accelerometers in the head of the dummy. For the highest 50 ms, the number was computed to be 185. This is well below the critical value of 1000. (See Part VII, Discussion, for an analysis of this instrumentation data.)

Plate 3

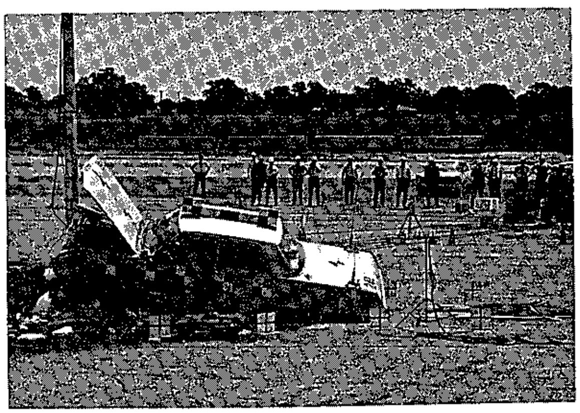


Impact + 0.027 Sec.



Impact + 0.231 Sec.

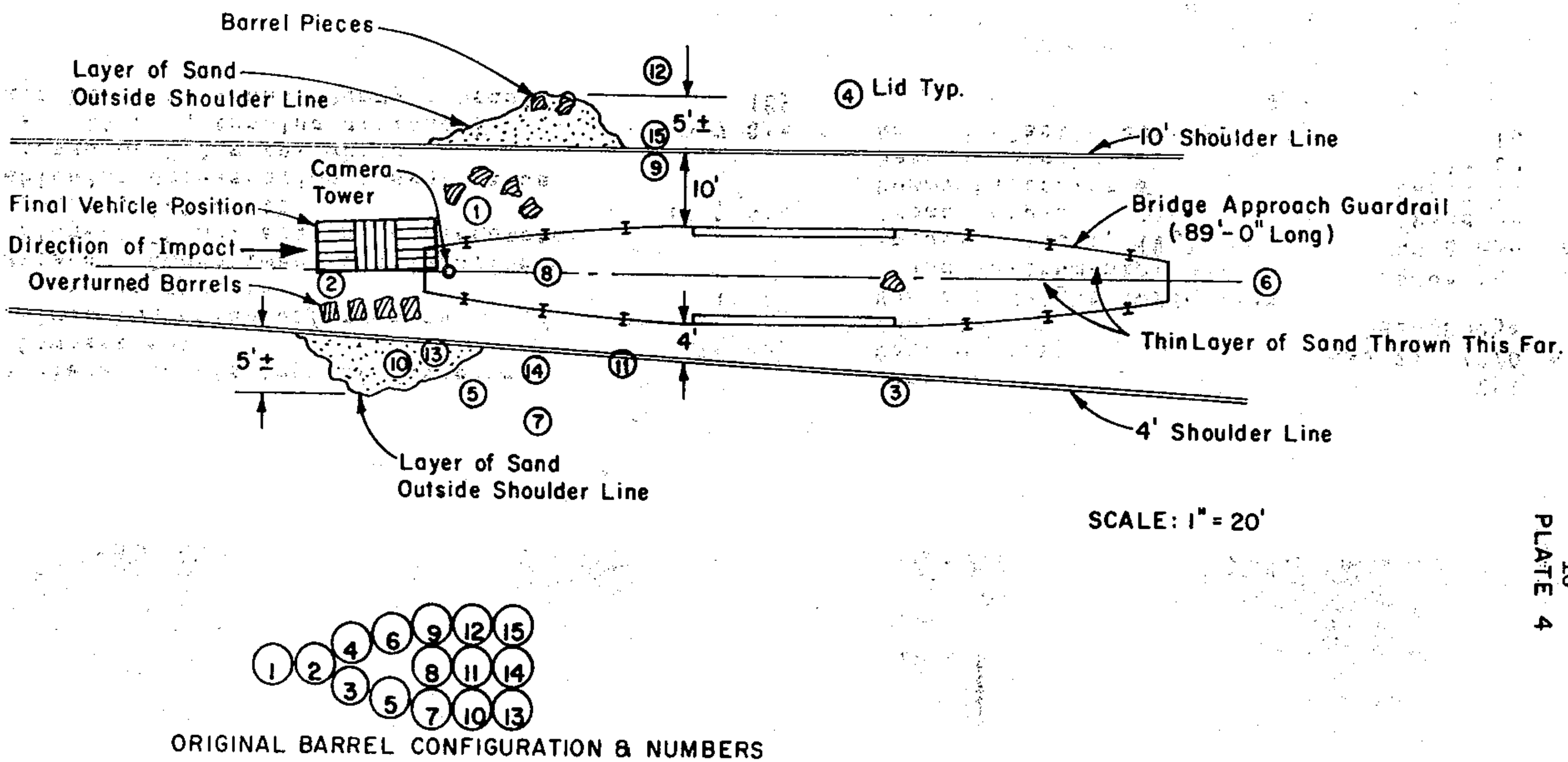
Impact + 0.435 Sec.



Impact + 2.373 Sec.

Test No.	241
Date of Test	May 21, 1970
Vehicle	1968 Dodge
Vehicle Weight (w/dummies and Instrumentation)	4690 lb.
Impact Velocity (V_o)	58.0 mph
Impact Angle	Head-on
Dummy Restraint	Lap Belt
Barrier Depth	21'-10"
No. of Plastic Barrels	15

Deceleration Distance of Passenger Compartment	24'-0"
Maximum Vehicular Deformation at Forestructure	1'-8"
Passenger Compartment Deceleration - Highest 50 ms. avg. - accelerometer record, 100 Hertz	10.7 G's
Vehicular Deceleration - Avg. value based on $V_o^2 = 2as$ where s = 24.0' (stopping distance)	4.7 G's
Gadd Severity Index (Dummy's head)	185



DEBRIS LOCATION DIAGRAM
TEST 241

Test 242

Barrier Description

The test barrier consisted of 17 plastic barrels filled with varied amounts of sand ranging from 200 lbs. at the nose of the barrier to 1400 lbs. at the rear (see Exhibit 1 and Figures 9 and 10). The black tape on the barrels shows the bottom level of sand in the rear barrels and top and bottom levels in the front barrels. The above weights are nominal for an assumed sand density of 100 pcf. Since it was determined that the actual (moist) sand density for Test 241 was only 80 pcf, sand that had been run through a dryer just prior to delivery was used for Test 242. This sand had a higher density of 88 pcf (moisture content of 0.4%). The plastic barrel components were all identical to those used for Test 241.

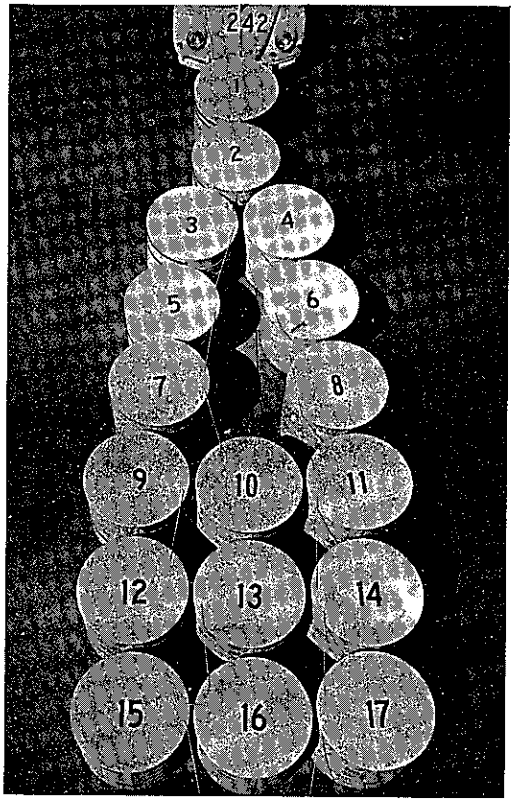


FIGURE 9

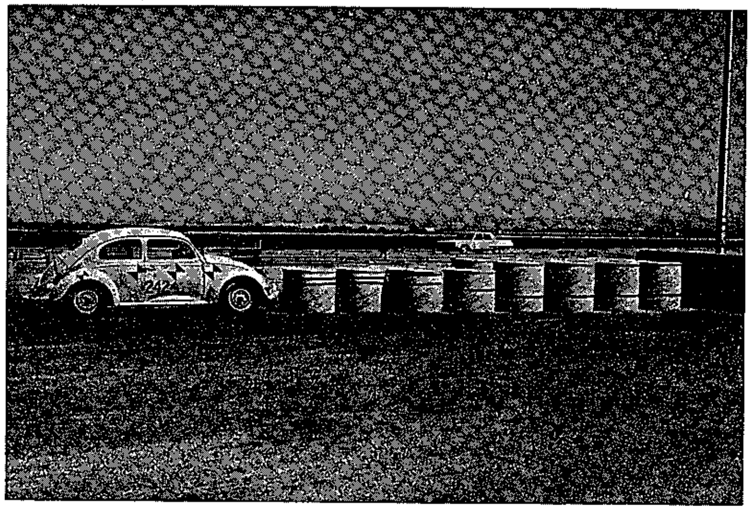


FIGURE 10

The barrier was lengthened from 21 ft (Test 241) to 24 ft (nominal) and the barrel weights were decreased at the nose to provide a softer impact. Also, the rear barrels were changed from 2100 lbs. to 1400 lbs. and the void space at the rear increased from 1 ft to 2 ft in an attempt to lessen the accumulation of sand and debris against the fixed object which had caused ramping in Test 241. A section of New Jersey concrete median barrier was used as the fixed object instead of the bridge rail because of the location of the ground anchors for the cable tow system used in this test.

Cotton sash cord was threaded through two small holes in the lid of each barrel. The cord was continuous through all 17 lids and was tied to the camera tower to prevent the lids from sailing onto the traveled way after impact as had occurred during Test 241.

Test Vehicle

A 1940 lb. 1957 Volkswagen sedan was used for the test vehicle. The 1940 lb. weight included a 165 lb. dummy which was restrained in the driver's seat with a lap belt, the gas tank filled with water, the spare tire (in front), and all the equipment used for radio control. The left door was replaced with a small steel channel brace so the action of the dummy could be recorded by the cameras.

Vehicle Behavior and Damage

See Plate 5, page 21, for a summary of the test results. The VW hit the barrier nose head-on with its axis about 9 in. to the left of the barrier center line. The impact velocity was 59 mph. The vehicle came to rest 19 ft beyond the nose of the barrier with all its wheels on the ground (Figures 11 and 12). During impact there was a 1'-4" rise at the rear of the vehicle (measured at a target on the right rear fender).

FIGURE 11

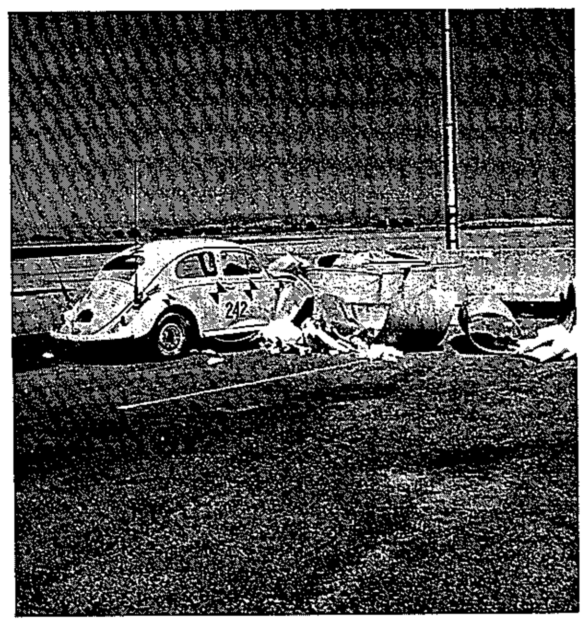


FIGURE 12

The front trunk lid remained closed and was moderately buckled, as were the front fenders. Maximum crush at the forestructure was only 8 in. (see Exhibit 3 and Figure 13). The entire windshield popped out due to the impact from the dummy's head. The substitution of a pulley for the standard VW steering wheel (required for radio control of the VW) prevented measurement of any steering wheel deformation.

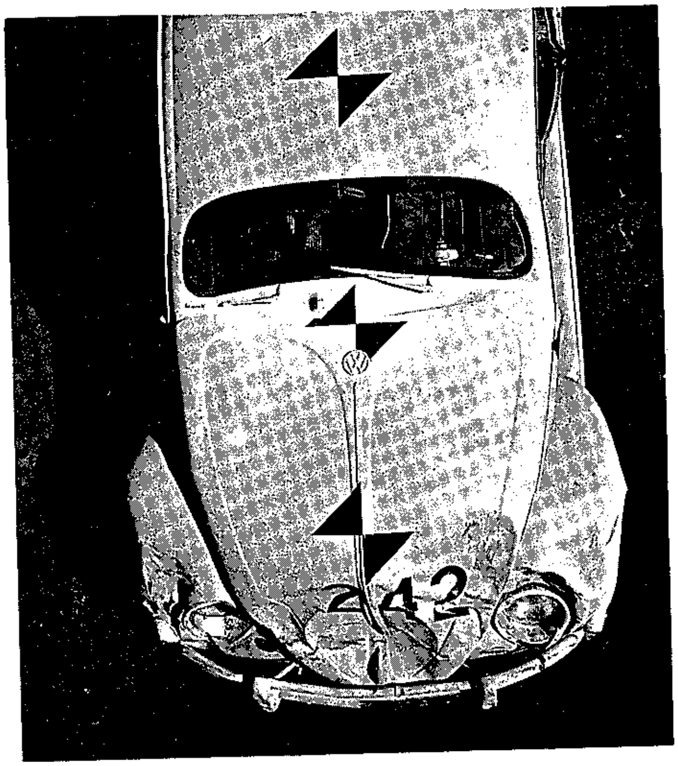


FIGURE 13

Barrier Damage

Plate 6, page 22, shows the location of the barrier debris. A small number of barrel core pieces were under the VW but there was no other debris under or behind it. There was no debris outside the 10 ft shoulder line but a small amount extended 9 ft beyond the 4 ft shoulder line. There was no sand covering the front of the VW. Very little debris was found beyond the back of the barrier. The lids all remained attached to the cotton rope and were clustered near the rear of the barrier. At least nine of the barrels were totally destroyed; four or five barrels were compressed but unbroken so they could have been reused; however, some of their inner foam plastic cores were crushed; three barrels were undamaged and undisturbed. The compressed barrels had moved forward during impact; it is unknown whether they could have been dragged on the ground and repositioned without breaking the plastic barrels and cores or spilling the sand.

Instrumentation Results

The highest average values of deceleration, based on filtered Visicorder traces, were as follows:

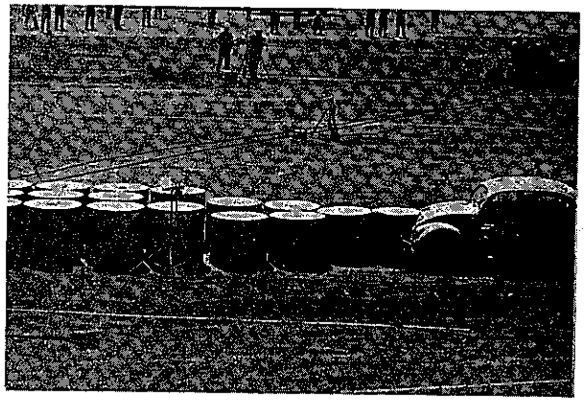
1. Vehicle - longitudinal - highest 50 ms avg. (2 accelerometers) — 8.7 G's

2. Dummy driver - head - highest 50 ms avg. (resultant of long., lat., and vert accelerometers at the same times after impact) — 44.0 G's

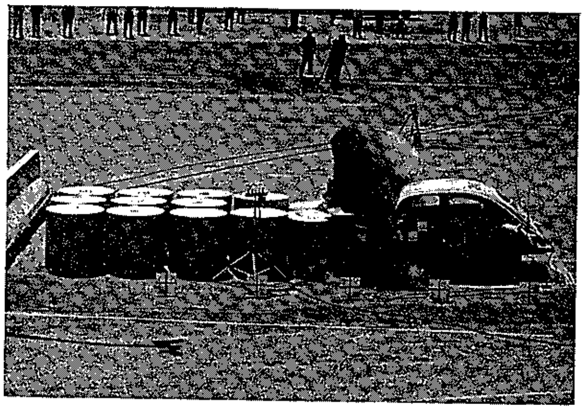
Vehicular lateral decelerations (2 accelerometers) were about 2 G's maximum for 5 ms with one ms ringing spikes of 8-10 G's. The seat belt force transducer was inoperable. The Gadd Severity Index was computed to be 1280, significantly greater than the critical value of 1000.

See Section VII, Discussion, for a discussion of the instrumentation results.

Plate 5



Impact + 0.022 Sec.



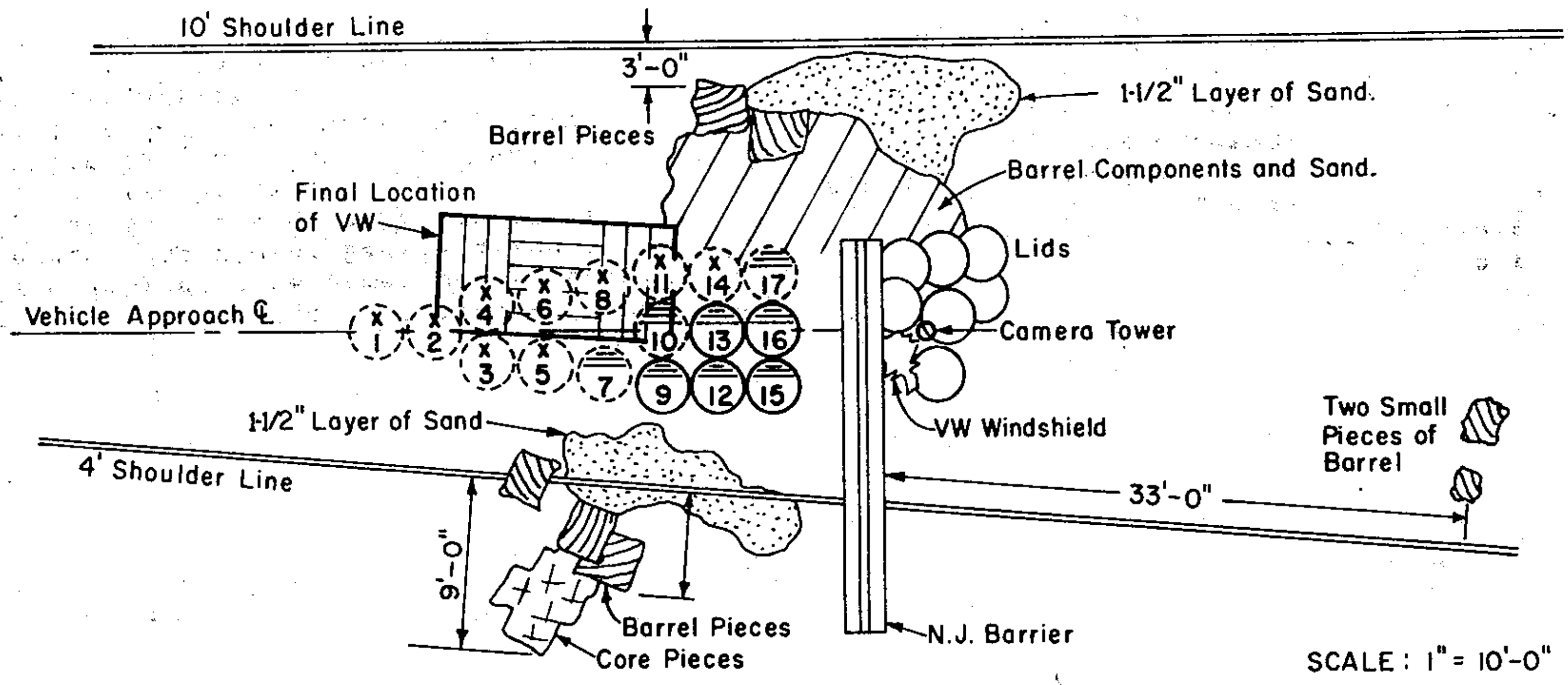
Impact + 0.163 Sec.

Impact + 0.586 Sec.

Impact + 4.536 Sec.

Test No.	242
Date of Test	September 4, 1970
Vehicle	1957 Volkswagen Sedan
Vehicle Weight (w/dummy & Instrumentation)	1940 lbs.
Impact Velocity (V_o)	59.0 mph
Impact Angle	Head-on
Dummy Restraint	Lap belt
Barrier Depth	25'-3"
No. of Plastic Barrels	17

Deceleration Distance - Passenger Compartment	19'-0"
Maximum Vehicular Deformation at Forestructure	8"
Passenger Compartment Deceleration - Highest 50 ms. avg. - Accelerometer Record, 176 Hertz	8.7 G's
Vehicular Deceleration = Avg. value based on $V_o^2 = 2as$ where s = 19.0' (stopping distance)	6.1 G's
Gadd Severity Index (Dummy's head)	1280



NOTES:

1. Barrels 9, 12, 13, 15, & 16 were all intact with lids on; two were slightly compressed. No. 16 was 9" from N.J. Barrier.
2. Barrels with an (X) were broken and thrown out of position.
3. All lids remained tied together.
4. Small number of core pieces under car.
5. All 4 wheels of VW on ground.
6. Barrels 7 & 10 were compressed but unbroken, lids were off.
7. Barrel 17 was compressed, unbroken, lid off, leaning against N.J. Barrier.

DEBRIS LOCATION DIAGRAM
TEST 242

Test 243

Barrier Description

The test barrier had the same size, number, and configuration of barrels as was used for Test 242 (Figures 14-16). As in Test 242, the sand was dried prior to delivery. It had a density of 89.2 pcf and a moisture content of 0.8%.

Lids were attached to the barrels with four equidistant pop-rivets according to the manufacturer's directions. Three extra rivets were added in a short row next to one of these four rivets. This row of rivets was randomly located and was not on the same side of all the barrels. It was hoped that these extra rivets would provide a hinge effect and minimize the wide scattering of lids that occurred during Test 241.

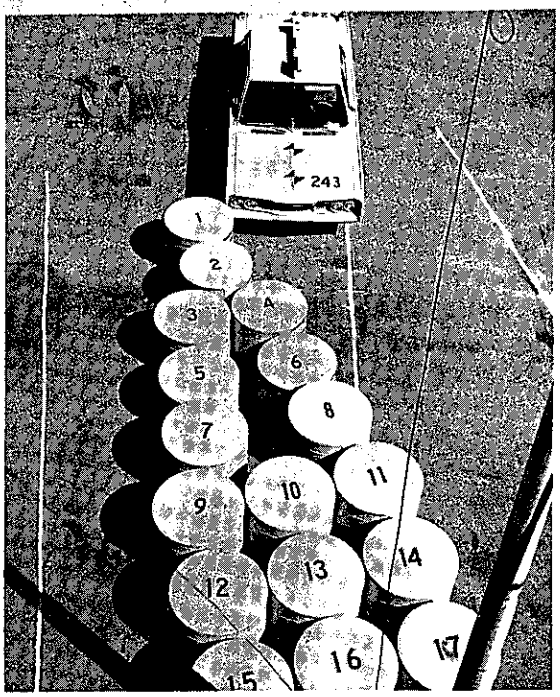


FIGURE 14

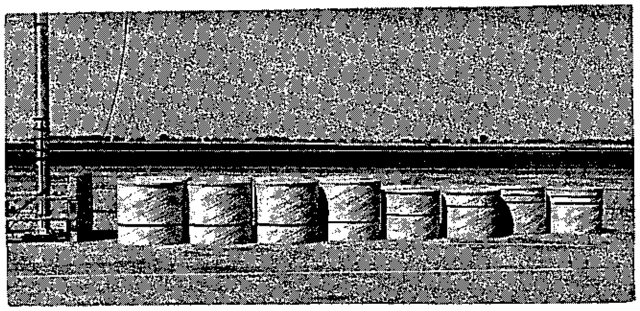


FIGURE 15

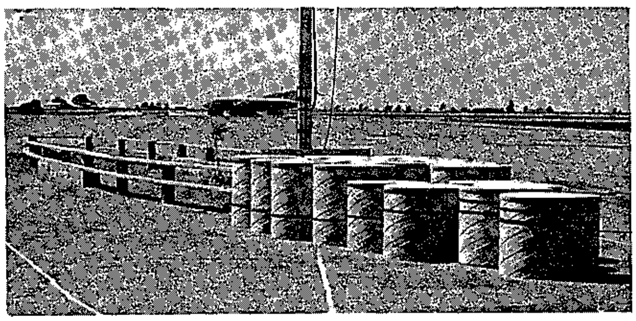


FIGURE 16

Test Vehicle

A 4770 lb. 1968 Dodge sedan was used as the test vehicle. The vehicle weight included a 165 lb. dummy restrained in the driver's seat with a lap belt, the water-filled gas tank, and all the radio control equipment.

Vehicle Behavior and Damage

See Plate 7, page 26, for a summary of the test results. The crash vehicle hit the nose of the barrier about a foot to the right of the planned point of impact at a speed of 57 mph and angle of 15° with the barrier axis. It ramped up midway into the barrier and continued on over and through it, narrowly passed by the right corner of the Type 8 bridge approach guardrail nose, and stopped with the rear of the vehicle even with the last row of barrels in the barrier. It came to rest with all wheels on the ground on a thin layer of sand (Figures 17 and 18).

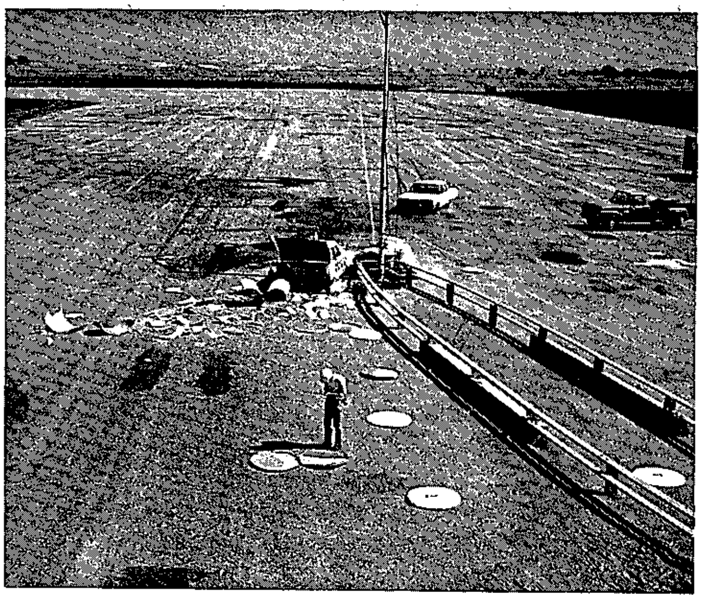


FIGURE 17

FIGURE 18

Damage to the vehicle forestructure was quite severe (Figure 19). The front end, including fenders, was uniformly crushed back against the engine. The maximum crush was 1'-9" (Exhibit 3). The engine was not displaced. The lower longitudinal front frame members and the bumper were sharply buckled down to the ground and back against the front wheels. The hood was undamaged due to the relatively low 30 in. height of the first four rows of barrels. A

FIGURE 19

crimp in the roof was observed on the driver's side above the door post. The rest of the car was undamaged. Maximum deformation of the steering wheel was 2-3/4 in. The collapsible steering column was foreshortened 0.75 in. due to impact by the dummy.

Barrier Damage

Four barrels remained standing at the rear corner of the barrier. Of these, only two were undamaged. Large amounts of debris were scattered to the front and right front of the crash vehicle, some of which extended about 20 ft to the right of the 4 ft shoulder line and across the traffic lane (see Plate 8, page 27). The right front corner of the vehicle projected about 3 ft. into the traffic lane; the right rear was about 1 ft inside the shoulder line.

The barrel lids were thrown far ahead of the vehicle, as much as 67-70 feet beyond the back of the barrier; however, only 3-4 lids landed in the traffic lanes. One landed 26 ft to the left of the 10 ft shoulder line. The extra rivets on the lids did not appear to have any beneficial effect. This may have been due, in part, to the lack of a washer on the rivet inside the barrel, a physically impossible condition. Therefore, the rivets had negligible resistance to the pullout forces generated by the impact.

A large number of broken foam core pieces was found under the crash vehicle and many other pieces were thrown beyond the vehicle. These latter pieces were immediately blown freely about by a moderate wind and could have posed a psychological hazard had they been blowing across traffic lanes.

Instrumentation Results

The highest average values of deceleration were as follows:

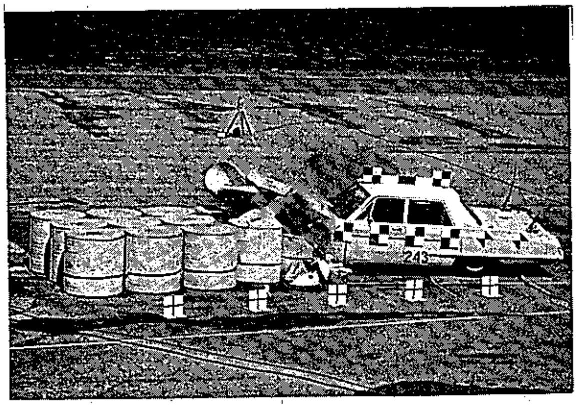
1.	Vehicle - longitudinal - highest 50 ms avg.	7.9 G's
2.	Dummy driver - head - highest 50 ms avg. (resultant of long., lat., and vert. accelerometers)	34.0 G's

The seat belt force transducer had a maximum reading of 600 lbs. Vehicular lateral decelerations (2 accelerometers) were about 3 G's max. for 5 ms with 1 ms spikes up to 10 G's. The Gadd Severity Index was 580.

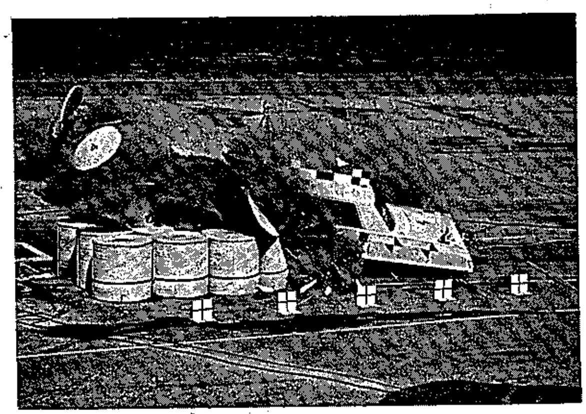
See Section VII, Discussion, for additional comments on these instrumentation results.

Plate 7

Impact + 0.012 Sec.



Impact + 0.180 Sec.

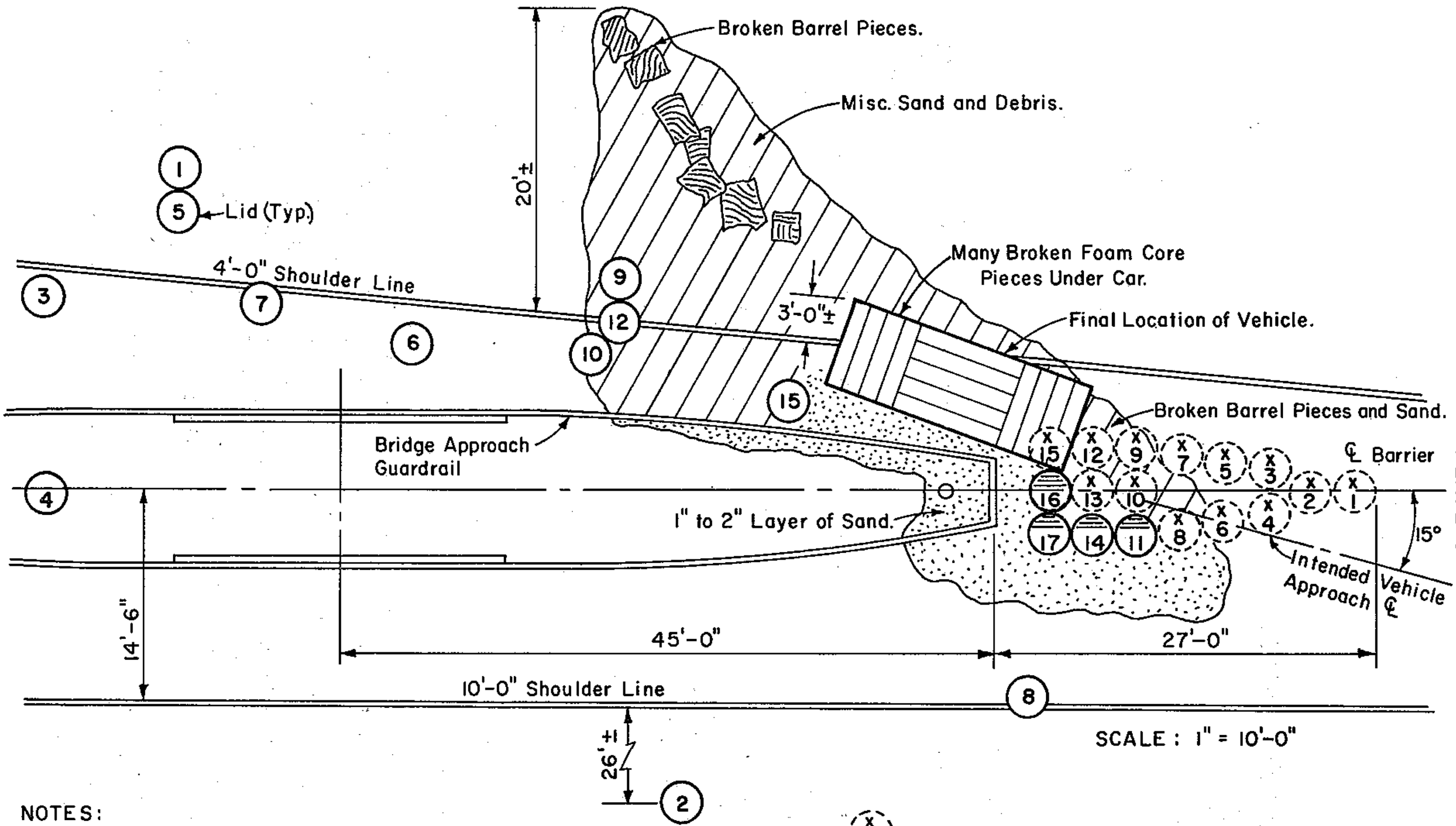


Impact + 0.348 Sec.

Impact + 8.880 Sec.

Test No.	243
Date of Test	September 24, 1970
Vehicle	1968 Dodge
Vehicle Weight (w/dummy & instrumentation)	4770 lbs.
Impact Velocity (V_o)	57 mph
Impact Angle	15° nose
Dummy Restraint	Lap belt
Barrier Depth	25'-3"
No. of Plastic Barrels	17

Deceleration Distance - Passenger Compartment	39'-0"
Maximum Vehicular Deformation at Forestructure	1'-9"
Passenger Compartment Deceleration - Highest 50 ms. avg. - accelerometer record, 176 Hertz	7.9 G's
Vehicular Deceleration - Avg. value based on $V_o^2 = 2as$ where s = 39'-0" (stopping distance)	2.8 G's
Gadd Severity Index (Dummy's head)	580



NOTES:
1. Many small, broken foam core pieces blown in all directions by wind.
2. Barrels 11, 14, 16 & 17 still upright, but squashed out of shape with lids still on.
3. Vehicle struck barrier 1 foot to right of intended vehicle approach centerline.
4. x indicates barrel was demolished.
5. Shoulder width measured at last row of barrels.

DEBRIS LOCATION DIAGRAM
TEST 243

VII. DISCUSSION

Summary of Test Parameters

Test Vehicle

Item	Test 241	Test 242	Test 243
Make	1968 Dodge sedan	1957 VW sedan	1968 Dodge sedan
Weight	4690 lbs.	1940 lbs.	4770 lbs.
Impact Velocity	58 mph	59 mph	57 mph
Type of Impact	Head-on	Head-on	Nose, 15° angle with barrier centerline
Dummy Restraint	Lap belt	Lap belt	Lap belt

Test Barrier

Item	Test 241	Test 242	Test 243
Nominal Length	21 ft	25 ft	25 ft
Space between Barrier and Fixed Object	1 ft.	2 ft	2 ft
Number of Cylinders	15	17	17
Nominal Weight of Cylinders	400-2100 lbs.	200-1400 lbs.	200-1400 lbs.
Density of Sand	80 pcf	88 pcf	89 pcf

Vehicular Deceleration

The records of vehicular longitudinal deceleration for Test 242 contained four distinct pulses spaced about 50 milliseconds apart. All were in the 10 G range with valleys of about 5 G's. This pulsing occurred as the vehicle went from one row of barrels to the next. The over-all shape of the deceleration data indicated that this barrier configuration (Test 242) was better than that used for Test 241 (a row of 2- 700 lb. barrels followed by 3- 1400 lb. barrels in the midsection of the barrier). This abrupt change in barrier mass for Test 241 coincided with the 15 G 5 ms vehicular deceleration which occurred as the vehicle passed the midsection of the barrier. For Test 242, the midsection of the barrier had 2- 700 lb. barrels followed by 2- 1400 lb. barrels and then by 3- 1400 lb. barrels -- a smoother transition of mass which was reflected in the deceleration data.

The vehicular longitudinal decelerations for Test 243 were fairly constant at 7-9 G's with several main pulses and were similar in magnitude and shape to those for Test 242, thus showing that the barrier configuration, which was identical for both tests, had a similar effect on cars with different weights. The deceleration pulse was decaying as the vehicle passed through the last two rows of 1400 lb. barrels; thus it appeared that these last rows had already been set in motion by the time the vehicle passed through them and, therefore, had a low decelerative effect. The vehicle had a velocity of about 14 mph as it penetrated the last row of barrels; hence, the barrier did not have enough mass and/or width to stop a 4770 lb. vehicle impacting near the nose at 15° and 57 mph.

A summary of the vehicular passenger compartment highest 50 ms average decelerations measured during each test is shown in Table 1 below. (The lateral decelerations measured were negligible so only the longitudinal decelerations are presented here.)

TABLE 1

Test	Highest 50 millisecond average values of longitudinal deceleration in G's
241 (one accelerometer)	10.7
242 (average of two accelerometers)	8.7
243 (average of two accelerometers)	7.9

The severity of these decelerations can be interpreted by comparing them with the recommended 200 ms deceleration tolerance limits proposed by Cornell[8]. These Cornell limits, which were 5 G's, 10 G's, and 25 G's for unrestrained, lap belted, and fully restrained occupants, define what would be, in the opinion of the researchers, a survivable environment under almost all circumstances when applied to a 50 ms time interval. Thus the vehicular passenger compartment decelerations in the longitudinal direction were judged acceptable for restrained passengers. Only in Test 241 did the computed value slightly exceed the maximum value of 10 G's for lap belted passengers. The vehicular decelerations were also under the value of 12 G's for the highest 40 ms period, another criterion often used to evaluate collision severity[7].

Computed values of the Gadd Severity Index indicate that in one test, Test 242, the dummy driver might have suffered fatal head injuries. Therefore, acceptable vehicular decelerations, based on the criteria described above, do not automatically confer immunity to fatal injuries.

Gadd Severity Index

Longitudinal, lateral, and vertical components of deceleration from the dummy's head were vectorially combined at identical times after impact (at successive 0.0025 second increments) to obtain resultant values of deceleration. Then the Gadd Severity Index[9], ($\int_{t_1}^{t_2} a^{2.5}\, dt$) was computed over the 50 millisecond period with the highest average resultant values of head deceleration using 20 successive time intervals with dt = 0.0025 sec. Table II, below, contains a summary of the Severity Indices calculated for the tests reported herein:

TABLE II

Gadd Severity Index

Test Number	Gadd Severity Index
241	185
242	1280
243	580
Recommended Tolerance Limit (1-50 ms Pulse Duration)	1000

The Gadd Severity Index of 1280 in Test 242 indicated that even a lap-belt restrained passenger probably would have suffered fatal head injuries if his head struck the windshield frame as violently as did the head of the dummy. This high number was not surprising in that the head of the dummy broke the windshield and forced it entirely out of the car, then went on to make a dent near the small radius edge of the unpadded stiff metal dashboard. The steering wheel had been removed to accommodate the remote steering aparatus. If it had been in place, it might have minimized the impact severity when the dummy struck the dash; however, a front seat passenger with no steering wheel in front of him, might normally impact the dash like the dummy driver did. This reinforces the idea that the injuries sustained by the vehicle occupants in a 60 mph collision with an energy absorbing barrier are dependent on the impact protection provided by the vehicle interior surfaces if ejection does not occur and both a lap belt and a shoulder harness are not in use. See Appendix D, Reference 5, for a discussion of this Severity Index and the tolerance of the human head to deceleration.

Debris

In all tests, the foam plastic core material that supported the sand in the barrels was broken into small pieces. This material did not land in the traveled way initially, except after the angular impact in Test 243; however, the pieces were so light that the slightest breeze blew them all over the test site. If this material was used in operational barrier installations, it could pose a severe litter and maintenance problem after barrier impacts. In addition, this material could create a psychological hazard to nearby motorists, even though it is lightweight and harmless.

The barrel lids were another source of debris. After impact, they sailed through the air for distances up to 100 feet. Most of them stayed in the gore area during the head-on impacts but the few which landed in the traveled way posed a potential psychological hazard for nearby motorists. In Test 242, the cotton sash cord which was threaded continuously through all the lids and anchored at the rear of the barrier proved to be an effective method of keeping all the lids in the gore area. However, the cord gave the barrier a slightly less desirable appearance.

Broken barrel pieces and sand were mostly contained in the gore area except during the angular impact of Test 243. In Tests 241 and 243 the Dodges tended to ramp over that debris, especially so in Test 241 where the rear of the barrier was only 12 in. from the bridge approach guardrail. The VW did not ramp up because of the sloping forestructure of the vehicle, which tended to nose under the sand in the front barrels of the barrier. The debris scattered in the traveled way after an angular impact such as Test 243 appears to be one presently unsolved drawback of this barrier.

Barrier Dimensions

The test barriers were close to the minimum length required to provide reasonable safety for restrained passengers in vehicles impacting at 60 mph, based on the instrumentation data results. The barrier could be increased in length to provide a softer impact; however, this would remove possible recovery area. Site conditions would partially govern the decision regarding optimum barrier length; initial and maintenance costs would vary with the length of the barrier.

Redirection

In all the tests, including Test 243 which involved an angular impact, the vehicle was not redirected but continued on a straight course after impacting the barrier.

Sand Density

The sand used in the barrels was sampled during barrier construction. Subsequent test results indicated that the density was significantly lower than the nominal 100 pcf unit weight assumed by the manufacturer, as can be seen in Table III, below:

TABLE III

Sand Density

	Density	Water Content
Manufacturer	100 pcf (assumed)	Unspecified
Test No. 241	80 pcf	7.6%
Test No. 242	88 pcf*	0.4%*
Test No. 243	89 pcf*	0.8%*

* Sand was run through a dryer just before delivery.

Reference 10 gives the general range of unit weights for dry, loose sand as 90-100 pcf, and for damp loose sand as 85-95 pcf. Thus, the sand used for the barriers tested fell just below the lower end of the normal weight range. Reference 10 also contains graphs showing how sand volume increases by 15 to 35% (max.) for coarse to fine sand, respectively, with moisture contents from 0 - 20%.

It was concluded that it would probably be too bothersome and an added expense to have sand dried for operational barriers. The added weight of the dried sand would not change the effectiveness of the barrier significantly; however, it is well to realize that sand density is a variable factor and that if sand with a density of 100 pcf was used in a barrier, the performance could differ somewhat from that reported herein.

Aesthetics

This barrier presents a low, relatively uniform shape. The barrels can be ordered in bright or dark colors. Care should be taken to provide a level site so that the barrels will not lean at random angles. For those who do object to the imposition of bright cylindrical shapes on the streamlined highway profile, a cover for the entire barrier might be desirable. Any cover selected should be a weather resistant, taut, flexible material and should not inhibit the free movement of the sand during impacts. Material wrapped around the sides would be preferable to a complete cover until full scale tests of barriers with covered tops are conducted.

Accident Experience

Accident reports from Connecticut indicate that fifteen in-service barriers were impacted sixteen times[3]. In thirteen cases, the vehicle was driven away before accident information could be gathered. Several of these impacts were nuisance hits. However, it was reported that the barrier may have prevented an impending collision with a fixed object in many of these cases. The three remaining reported accidents were all serious, yet in all cases the drivers received only minor injuries and it was clear that the barrier prevented a calamitous crash into the fixed object.

The manufacturer reported that as of May 1, 1971, there were 135 barrier installations in 20 states and two foreign countries[11]. There had been 81 impacts of the barrier at speeds up to 65 mph with one injury. In 80% of these impacts, the vehicle was driven away and the accident was not reported.

Design Considerations

Barrier size and configuration must be selected for each site. The barrier configuration will depend on (1) the width of fixed object to be shielded, (2) the predicted speed and angle of the impacting vehicles, and (3) the available space in the gore, shoulders, and traffic lanes. The presence of curbs and guardrails may also affect the design. A curb immediately in front of the barrier nose could adversely affect the barrier performance because the vehicle may vault over the curb, thus preventing the vehicle from impacting the modules at the optimum height for vehicle stability and uniform deceleration. Such a curb should be removed.

The width of the back row of modules should always be greater than the width of the fixed object. This will soften the impacts of those vehicles striking the rear portion of the barrier at an angle and provide some deceleration prior to striking the corners, if any, of the fixed object. The barrier modules should be set back from the traffic lanes to minimize the number of casual vehicular contacts with the barrier and the amount of debris thrown into the traveled way when an impact does occur. Also, space should be left behind the last row of modules so the sand and debris will not be confined and increase the ramping effect of the vehicle.

The lower foot of sand in the 2100 lb. modules provides additional mass as a backup for the front of the barrier. However, the velocity of the vehicle at the time it makes direct contact with the back row of the barrier is not sufficient to explosively displace this sand. Consequently, it is displaced very little and thus tends to form a ramp. The use of 1400 lb. modules in place of 2100 lb. modules in the last row would therefore be desirable to eliminate this relatively ineffective lower foot of sand.

A recent report[3] stated that some nonimpact failures of these cores had occurred when they were placed on sloped gore areas. The failures occurred only when the strong axis of the core material was perpendicular to the cross slope and consisted of collapse of the core. To prevent this, the strong axis of the foam plastic core blocks should be placed parallel to the cross slope to prevent collapse of the core due to barrel movement down the cross slope induced by traffic vibrations. Also, the manufacturer is studying new core block configurations and new core materials. It might prove advisable to enclose cores made of light, crushable foam plastic with a flexible fine-mesh bag to limit their scatter after a barrier impact.

If placed in climates subject to temperature below 32° F, the addition of at least 5% road salt to the sand should be specified to preclude solidification of the moist sand.

A thin wire or rope may be threaded continuously through all module lids and anchored to the ground at the rear of the barrier to minimize dispersal of lids during impact (Test 242).

A recommended minimum optimum barrier length would be 21 ft to 24 ft. This length provides survivable deceleration levels for 60 mph impacts without taking away excessive recovery area for errant vehicles.

VIII. REFERENCES

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10. "Concrete", Troxell and Davis, McGraw-Hill Engineering Series, 1956.

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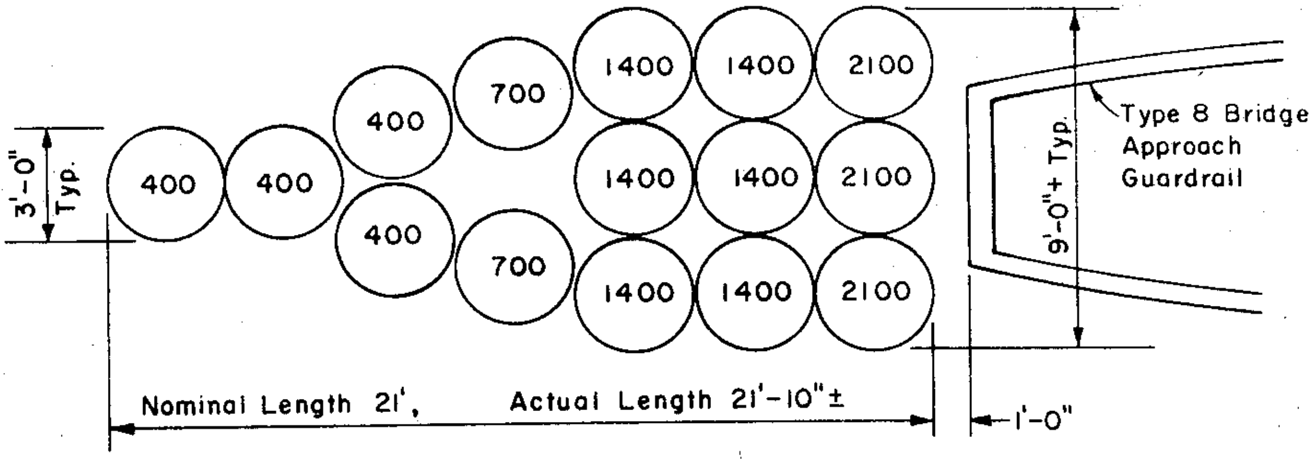
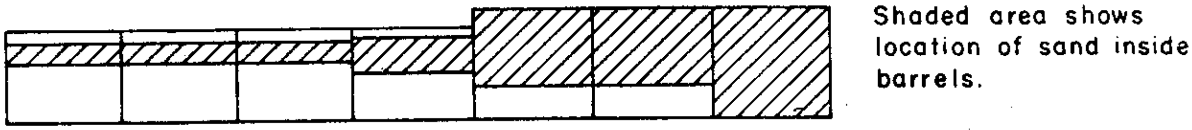
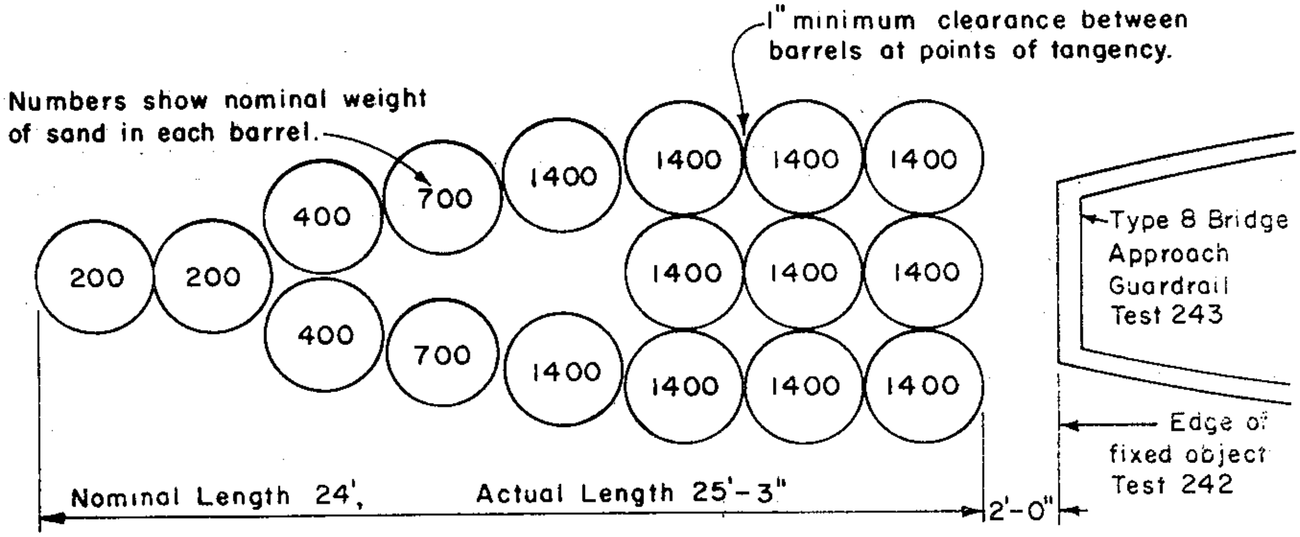
EXHIBIT 1



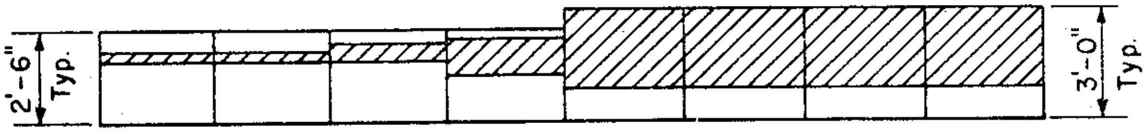
TEST NO. 241 PLAN VIEW



ELEVATION



TEST NOS 242 & 243 PLAN VIEW

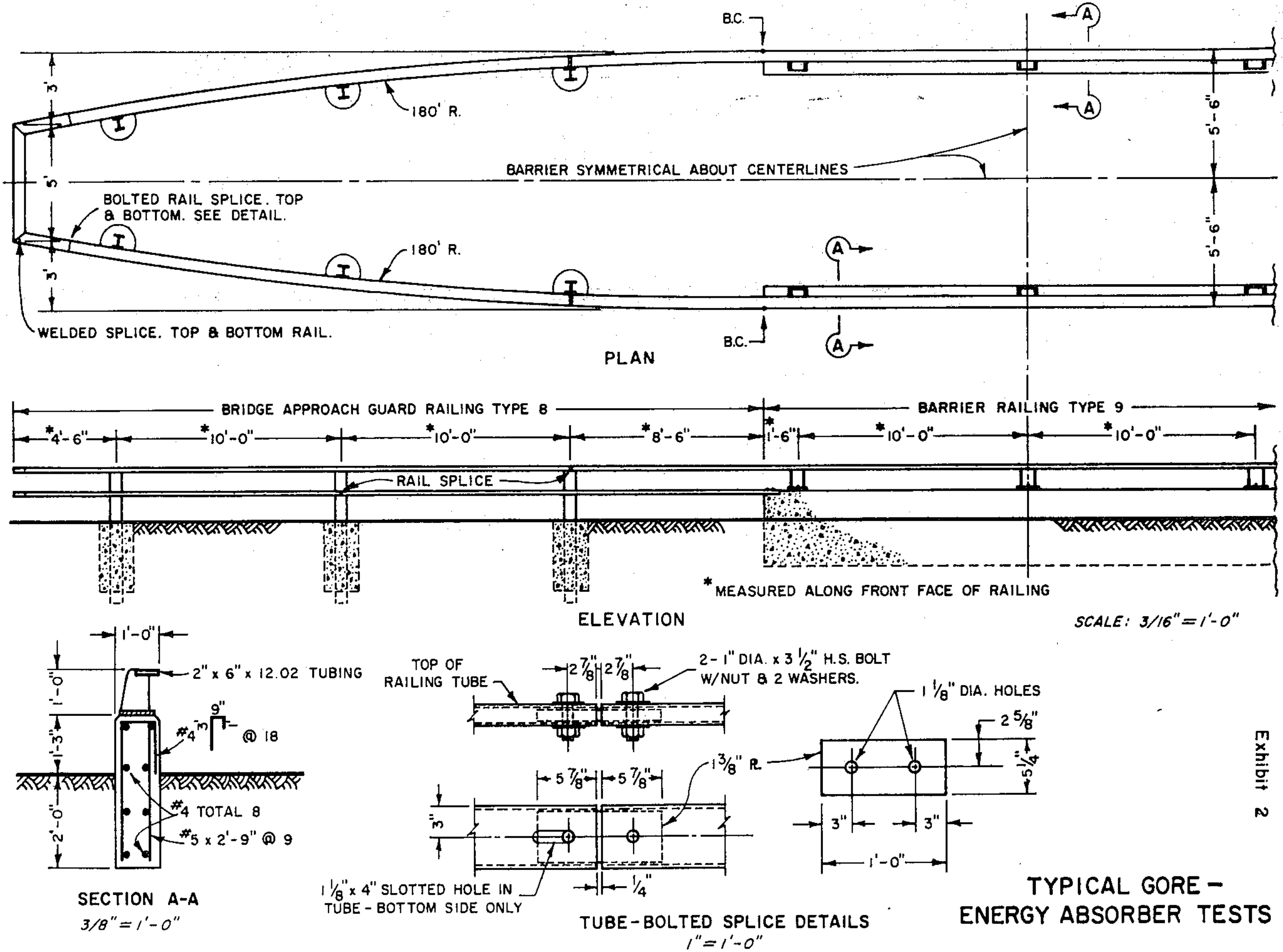


ELEVATION

SCALE: 1" = 5'-0"

TEST BARRIER PLANS

Exhibit 2

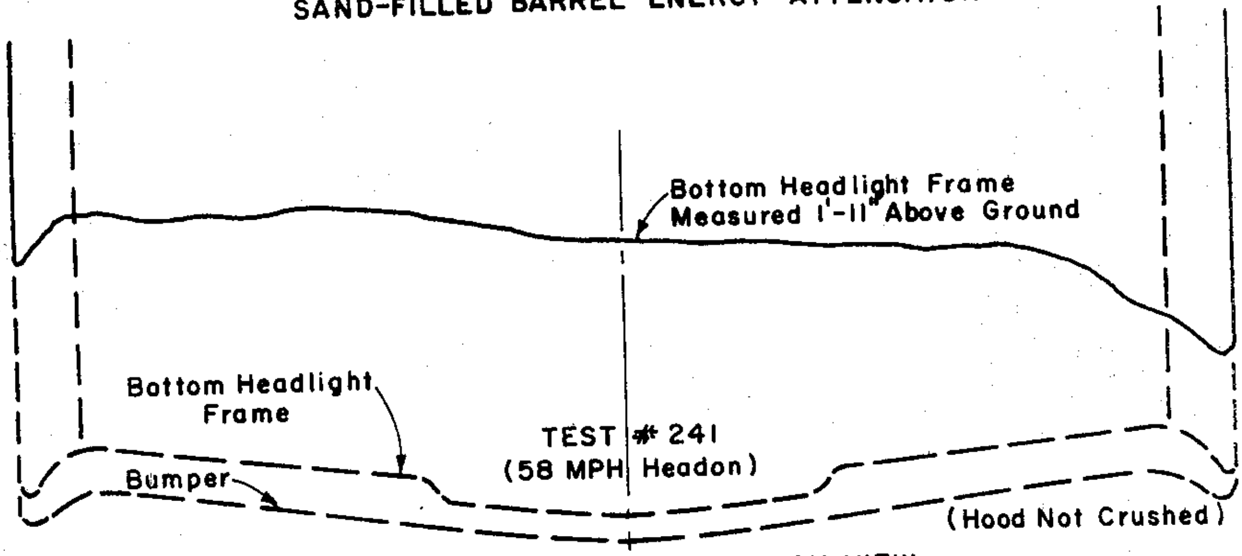


TYPICAL GORE – ENERGY ABSORBER TESTS

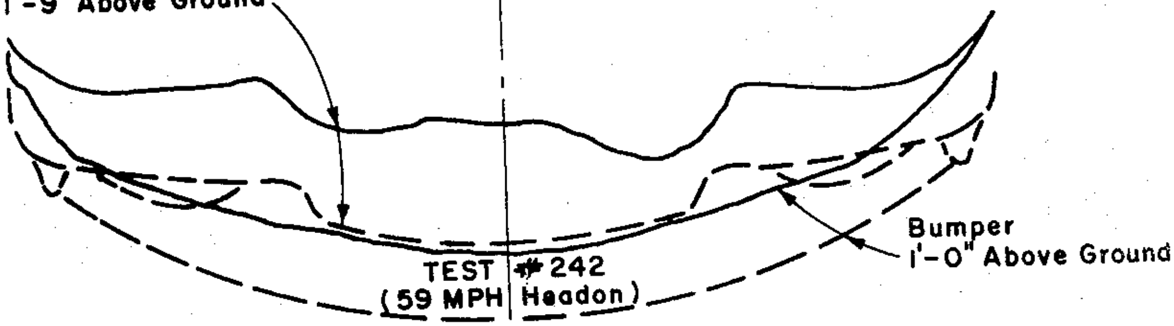
EXHIBIT 3

VEHICULAR CRUSH

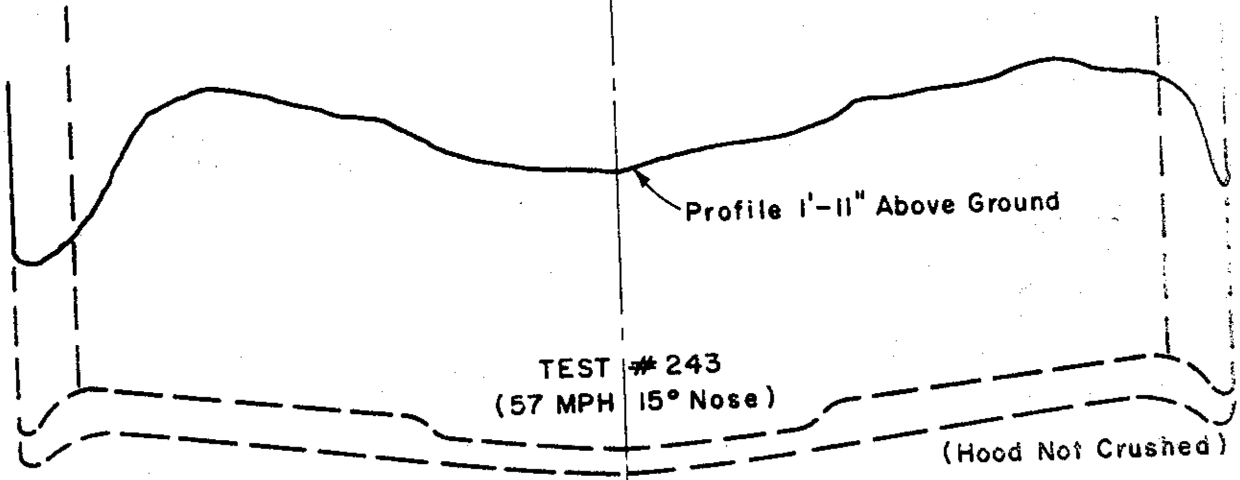
SAND-FILLED BARREL ENERGY ATTENUATOR



1968 DODGE-FRONT END-PLAN VIEW



1957 VW-FRONT END-PLAN VIEW



1968 DODGE-FRONT END-PLAN VIEW

Dashed lines show precrash profiles.

Scale 1" = 1'-0"